Southern Cross University
ePublications@SCU

School of Environment, Science and Engineering Papers

School of Environment, Science and Engineering

1988

Assessing site productivity of indigenous cypress pine forest in southern Queensland

Jerome K. Vanclay
Southern Cross University

N B. Henry
Department of Forestry, Queensland

Publication details

Vanclay, JK & Henry, NB 1988, 'Assessing site productivity of indigenous cypress pine forest in southern Queensland', *Commonwealth Forestry Review*, vol. 67, no. 1, pp. 53-64.
The abstract and pdf of the published article reproduced in ePublications@SCU with the permission of Commonwealth Forestry Review

ePublications@SCU is an electronic repository administered by Southern Cross University Library. Its goal is to capture and preserve the intellectual output of Southern Cross University authors and researchers, and to increase visibility and impact through open access to researchers around the world. For further information please contact epubs@scu.edu.au.

ASSESSING SITE PRODUCTIVITY OF INDIGENOUS CYPRESS PINE FOREST IN SOUTHERN QUEENSLAND

By J. K. Vanclay[1] and N. B. Henry[1]

SUMMARY

Site form, the expected height of a 25 cm d.b.h.o.b. tree predicted from the stand height-diameter relationship, is shown to be a practical and useful measure of site productivity in indigenous cypress pine (*Callitris* sp.) forests in southern Queensland. Unlike site index, this measure is not based on age and thus has potential for site productivity assessment in stands of unknown or uneven age.

RÉSUMÉ

Il est montré que la forme de station, la hauteur attendue d'un arbre de 25 cm de diamètre à hauteur d'homme (écorce incluse) prévue du rapport hauteur dominante-diamètre, est une mesure pratique et utile de la productivité de station dans les forêts indigènes de *Callitris* sp. du sud de Queensland. À la difference de l'indice de station, cette mesure n'est pas basée sur l'âge, donc elle a du potentiel pour l'évaluation de la productivité de station dans les populations inéquiennes ou d'âge inconnu.

RESUMEN

Se presenta la Forma de Sitio (Site Form), definida como la altura esperada de un árbol de 25 cm. de diámetro (dap), obtenida de la relación altura-diámetro del rodal, como un indicador práctico y útil de la productividad del sitio en bosques nativos de *Callitris* sp en el sur de Queensland. A diferencia del Indice de Sitio, esta medida no se basa en la edad y por tanto sería de utilidad en la evaluación de la productividad del sitio en rodales discetáneos o de edad desconocida.

Introduction

Efficient yield forecasting and forest management requires a reliable measure of site productivity. Site index is widely used as a measure of site productivity, but its use is confined to even-aged stands of known age.

This study is concerned with the indigenous white cypress pine *(Callitris glaucophylla* Thompson & Johnson syn *C. glauca* R. Br. ex R. T. Baker & H. G. Sm.) forests in southern Queensland. These forests commonly occur as uneven-aged stands dominated by cypress pine, and less commonly as pure even-aged stands.

The species forms growth rings, but apparently "annual" rings are confused by a profusion of "false" rings, and attempts to determine age are quite subjective (Fett and Smith 1975). In this respect it differs from the northern cypress pine *(C. intratropica* R. T. Baker & H. G. Sm.) which in the tropical monsoon climate of northern Australia forms annual rings amenable to stem analysis (Hammer 1981) allowing site index to be determined. Thus for stands of white cypress pine in southern Queensland site index cannot be used to quantify site productivity and some other measure is required.

[1] Department of Forestry, Queensland, Australia.

Review of the literature

Volume production is usually the growth parameter of greatest interest to the forest manager, and evaluation of site productivity in terms of volume is desirable (Sammi 1965). Some measure of volume production as a guide to site productivity in plantations is used in Germany (Shrivasta and Ulrich 1976), Sweden (Johnston *et al.*, 1967), and Britain (Johnston and Bradley 1963, Bradley *et al.*, 1966 also in many other countries *e.g.* France, Finland, Norway). Despite the superiority of volume production as an indicator of site productivity, site index based on height-age relationships has been widely adopted, principally because volume production is difficult to measure (Mader 1965). However, in stands of unknown or uneven age, some other measure of site productivity is required. Vanclay (1983) identified several measures which are potentially useful for assessing site productivity in indigenous forests. The more promising include visual appearance, natural basal area, stand height and site form.

The visual appearance of a stand may be used to indicate site productivity. Lewis *et al.*, (1976) reported that *Pinus radiata* plantations in South Australia can be classified successfully into seven site quality classes on the basis of general vigour and form, crown density, needle length and colour, bark tightness and colour, green level and degree of canopy formation. A 3% systematic sample of standing volume is assessed concurrently to calibrate the visual assessment. However, in indigenous forests of varying age and stocking, the method is unlikely to give results more precise than three classes, good, average and poor.

Pienaar and Turnbull (1973) observed that even-aged stands with initial spacings above a certain lower limit converge towards an identical amount of basal area per hectare, determined by the capacity of the site. If the premise that undisturbed sites tend toward equilibrium (Dawkins 1958) is accepted, then the equilibrium or natural basal area may be assumed to be an expression of the site's productivity (Assman 1961, MacLean and Bolsinger 1973, Adlard 1980). This measure may provide a useful indicator of site for relatively undisturbed forest, but because it is unreliable after logging or other disturbance, it is unlikely to have wide application.

Westveld (1933) argued that the height attained at the cessation of height growth was a good indicator of site productivity. Havel (1975, 1980) used stand height to estimate site productivity in jarrah *(Eucalyptus marginata)* forest in western Australia. The method fails if logging has removed the large stems from the stand, or if wind has broken the tops of the tallest trees.

Where suitably large stems are not available, the height-diameter relationship may be used to characterise the site. This approach is analogous to site index[1] and some authors (Stout and Shumway 1982, Reinhardt 1982, 1983) have used the height-diameter relationship to derive site index estimates compatible with previously published height-age relationships. Site index is undefined in an uneven-aged stand, and for species such as cypress pine which have unknown and indeterminate age, it is appropriate to use the expected height at a convenient index diameter. Vanclay (1983) proposed the term *site form* to distinguish the concept from site index.

McLintock and Bickford (1957) proposed an equation based on Meyer's (1940) adaptation of the Mitscherlich efficacy law (Assman 1961):

$$H = 1.3 + a(1 - e^{-bD})$$

where H is height (m), D is d.b.h. (cm), a is a site parameter and b is a constant characteristic to the species. Their work was based on dominant trees selected from

[1] Site index is usually defined as the expected height of the dominant trees in the stand at a nominated index age.

stands from a wide range of sites, but not from stands with abnormal stocking or recent logging. They used a series of anamorphic curves, assuming that site would affect only the parameter a.

The method was more formally quantified by Stout and Shumway (1982), who gave height-diameter equations which predict site index compatible with published height-age equations for six species in the U.S.A. Their data were also obtained from dominant and co-dominant trees, but taken only from even-aged stands. They examined the relationship of both parameters with site index, and found that only the asymptotic height a was correlated with site, and that the shape parameter b was constant for any species.

Reinhardt (1982) investigated several equations for the height diameter site relationship of western larch, and found that the relationship exhibited a strong polymorphic trend, best described by the Bertalanffy equation. Reinhardt's equation was:

$$H = 1.3 + a(1-e^{-bD})^c$$

where a and c are constants determined by the site, and b is a species constant. Reinhardt worked with data from pure and mixed stands of western larch, and used the height-diameter curve to predict site index compatible with the height-age equations of Bricknell (1970). Not only were trees on better sites taller at any given diameter than trees on poor sites, but the growth response exhibited a strong polymorphic trend. However, the curves were not well differentiated for trees less than 50 cm d.b.h., and data from trees exceeding that diameter were necessary to establish a reliable relationship. Reinhardt (1983) claimed that accuracy depended upon the variability of the site, but that reliable estimates of site index could be achieved by measuring five to fifteen trees.

Studies by Grimes and Pegg (1979) in spotted gum and ironbark forests in Queensland incorporated estimates of site form derived from hand fitted height-diameter curves. The resulting estimates were found to be reliable and consistent over long periods of time.

Data

During the periods 1937–40 and 1955–58, a total of 117 permanent sample plots were established in southern Queensland on three major cypress pine reserves (State Forests 154, 302 and 328, Figure 1) to gather information on the yield of managed forests. Some of these plots were located using systematic schemes with random starts. Others were based on a stratified sample of inventory plots also located using a systematic scheme with random starts.

The plots are *c.* 0.4 hectare (1 acre) rectangular plots subdivided into four quadrats on which each tree taller than *c.* 3 metres (10 feet) is individually numbered, tagged and measured. Measurements were initially carried out every 2–3 years, but the current prescription is to measure every 6 years. Additional measures are carried out at time of logging or silvicultural treatment. The d.b.h.o.b. of every stem is recorded at each measure, but heights and other parameters are recorded less frequently.

Additional data were derived from a series of thinning experiments (Johnston 1975) which were subjectively located in dense even-aged stands of cypress pine regeneration. The majority of these experiments were established during the period 1934–42, and include stands varying from 100 to 4 000 stems per hectare.

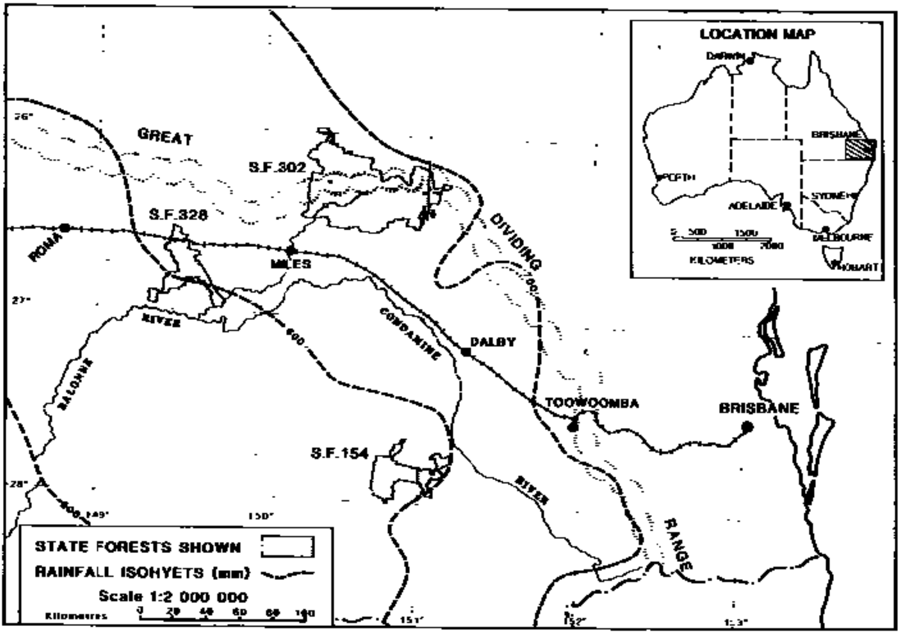

Figure 1. Location of Forests 154, 302 and 328.

Method

The height-diameter relationship in cypress pine was originally investigated as a possible component of a general volume equation (Anon 1979)[2]

$$V = -0.01514 - 0.006674\ SF + 0.4240\ BA\ SF \quad (1)$$

where V is merchantable volume (m^3), SF is site form (m) and BA is basal area (m^2). Investigation of site form *per se* was extended when it was found to have more general application as a measure of site productivity.

The index diameter chosen was 25 cm d.b.h., as trees of this diameter commonly occur in uneven aged stands, are generally still actively growing, and have a well defined conical and undamaged tip, enabling the site form to be determined more accurately.

The Mitscherlich equation:

$$H = a - be^{-cD} \quad (2)$$

was found suitable to describe the height-diameter relationship. By defining the parameter b as equal to a–1.3, the model is constrained to predict a height of 1.3 metres at zero d.b.h., and in this form can be easily fitted even to data sets with a very limited d.b.h. range. The model must also be constrained to pass through the index height at 25 cm d.b.h., and thus the parameter c must be defined as

2 The volume equation presented here is not the same as that published in 1979, but is a recent and previously unpublished revision.

$$c = -\frac{Log\left[\frac{a-SF}{a-1.3}\right]}{25}$$

Analysis of the available data reveals that the asymptote a is linearly related to site form:

$$a = -10.87 + 2.460\ SF \qquad (3)$$

The overall site form equation is illustrated in Figure 2. Site form can be determined graphically from this figure by plotting the heights and diameters of the individual trees, and subjectively determining the curve of best fit. It is more commonly determined analytically by fitting equation (2) using ordinary least squares.

Six stems within the range 20 to 30 cm d.b.h. are usually sufficient to establish an estimate of site form correct to the nearest metre. Up to ten stems may be required if no stems within this d.b.h. range are available. When the range of stem diameters lies within 20 to 30 cm d.b.h., a simple straight line regression of tree height on diameter can be used to determine site form without bias.

In practice, site form may vary from 10 to 20 metres, but stands of site form less than 14 m are rarely of commercial importance.

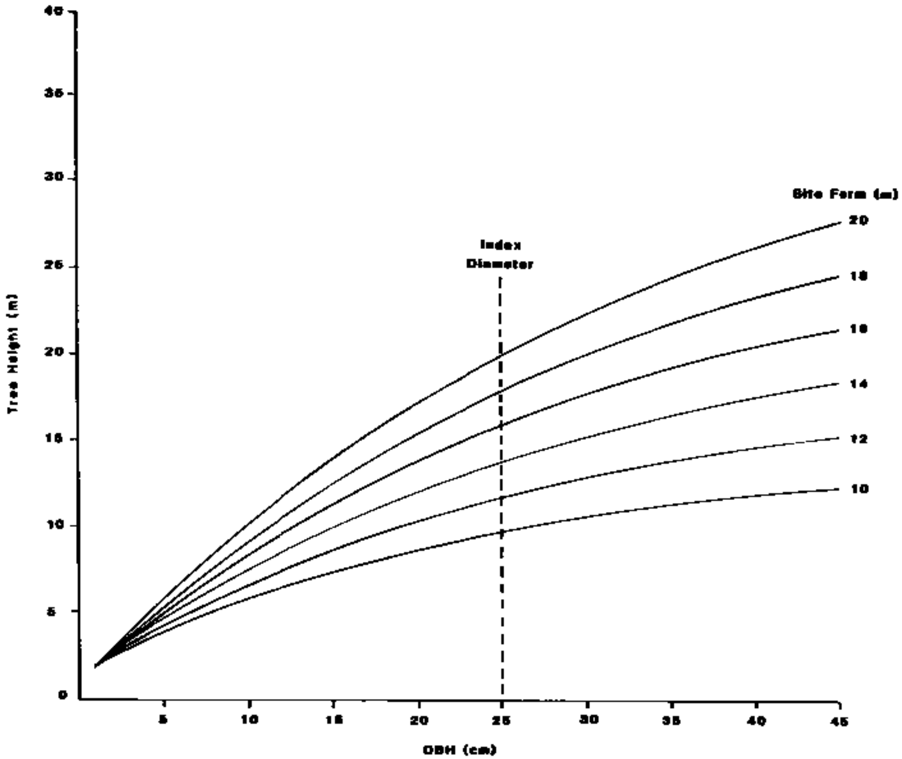

Figure 2. Cypress Pine Height-Diameter Relationship.

Comparison with other measures

Site form is comparable with several other measures of site productivity. The asymptote of the height-diameter relationship (*a* in equation 3) indicates the potential maximum stand height, which exhibits a linear relationship with site form. An indication of site index may be gained by comparing equation (2) with Hammer's (1981 Equation II) site index equation:

$$H = 1.3 + (1.284\ SI - 1.67)\ (1 - e^{-0.0302\ A}) \qquad (4)$$

where H is tree height (*m*), A is breast high age (*years*), and SI is site index age 50 (*m*). This equation was based on the two tallest dominant trees in each of 89 competitor polygons. The asymptotes of these two equations (3 and 4) may be related to allow comparison of site form with site index:

$$SI = -8.179 + 1.916\ SF \qquad (5)$$

where SI is the equivalent site index (*m*) with index age fifty years. However, this comparison may not be entirely valid as Hammer observed that northern cypress pine in the Northern Territory exhibited a different pattern of height growth to that of cypress pine in southern Queensland.

Table 1 indicates the correlation site form and several empirical measures of site productivity, based on observations on 416 quadrats:

- A subjective estimate of site quality (1 best, 4 poorest) recorded for each quadrat at plot establishment (1937 to 1955);
- The height of the tallest cypress pine tree observed on each quadrat at any time during the period of measurement;
- The highest basal area observed on each quadrat at any time during the period of measurement, used as an approximation to natural basal area;
- The gross periodic annual volume increment observed over the entire measurement period; and
- The species composition expressed as the percentages of the standing basal area as cypress pine and ironbark (*Eucalyptus crebra* F. Muell.) at plot establishment.

Table 1
Correlation between Estimates of Site Productivity.

Variable	SF m	SQ	H_{max} m	BA_{max} m^2ha^{-1}	VI $m^3ha^{-1}ann^{-1}$	Cypress %	Ironbark %
Site Form (*m*)	1.00						
Site Quality	–.29	1.00					
Max Height (*m*)	.70	–.40	1.00				
Max. Basal Area (m^2ha^{-1})	.46	–.21	.35	1.00			
Volume Inc. ($m^3ha^{-1}ann^{-1}$)	.40	–.34	.41	.41	1.00		
Cypress (% of BA)	.21	–.46	.51	–.03	.24	1.00	
Ironbark (% of BA)	–.19	.47	–.44	–.03	–.23	–.93	1.00

Table 1 reveals that site form has a stronger correlation with many other measures of site productivity (periodic annual volume increment, maximum observed tree height, maximum observed stand basal area) than does the subjective site quality. Gross periodic annual volume increment is the best indicator of site productivity, but only for fully stocked stands. The relatively poor correlations presented in Table 1 are due, in part, to the great variations in stocking and stand composition. The correlations given in Table 1 suggest that site form is no better than the maximum height or basal area, but the advantage of site form is that it can be estimated for all stands including understocked and young even-aged stands.

Discussion

Most previous work relevant to site form has used only the dominant and co-dominant trees. Our experience with the relatively lightly stocked (typically 150 to 500 stems/hectare) uneven-aged stands of cypress pine in southern Queensland suggests that it is more important to sample the full range of diameters available, especially near the index diameter, than it is to restrict sampling to some particular stand fraction. However, care should be taken to avoid trees with evidence of top damage.

For some parameter to be acceptable as a measure of site productivity, it must fulfill four criteria:

- It must be reproducible, and be consistent over long periods of time;
- It must be indicative of the site, and not be unduly influenced by stand condition or management history;
- It must be correlated with the site's productive potential; and
- It must be at least as good as, and preferably better than, any other productivity measures available.

Site form meets all these criteria, and has an additional advantage that it is easily determined from normal inventory measurements taken on a single occasion.

Estimates of site form in uneven-aged stands of cypress pine exhibit remarkable stability over long periods. Most of the plots produced estimates of site form which varied by less than one metre over the forty odd years of measurement. A few plots exhibited variations in estimated site form as small as 0.2 metres in four measurements over a fifteen year period, and only 3% of the plots exhibited variations exceeding two metres over the whole measurement period. Figure 3 illustrates the typical variation in estimates over the range of site form available.

Figure 4 illustrates variation in estimates of site form in even-aged stands following thinning from uniformly high densities in 1941. The depression in these curves in the late 1940s is due to damage caused by severe frosts on State Forest 328 during 1946. Frosts of such severity may be expected to occur less frequently than once in every fifty years (Strochnetter[3] pers comm, Hammer and Rosenthal 1978). By 1954 most plots appeared to have recovered from the damage incurred during 1946, allowing the stability of site form estimates over time to be appraised. Of the available data, 38 plots were maintained at constant stocking over the period 1954–1980, and were measured an average of 11 times during this period. Linear regression indicated that 21 plots experienced a significant increase in site form over time, 13 plots revealed no significant change, and 4 plots revealed a significant decrease in site form. The rate of change in site form averaged 1.3 cm/year (range + 5 to – 4 cm/year), and is not correlated with either stocking (stems/ha) or mean site form. Adjacent plots exhibited similar patterns of change in site form, suggesting a component of real site change.

Selective logging sometimes, but not always, influenced the estimate of site form by up to one metre more or less, at the time of logging. There was no relationship between time

[3] F. G. Strochnetter, Queensland Regional Office Bureau of Meterology.

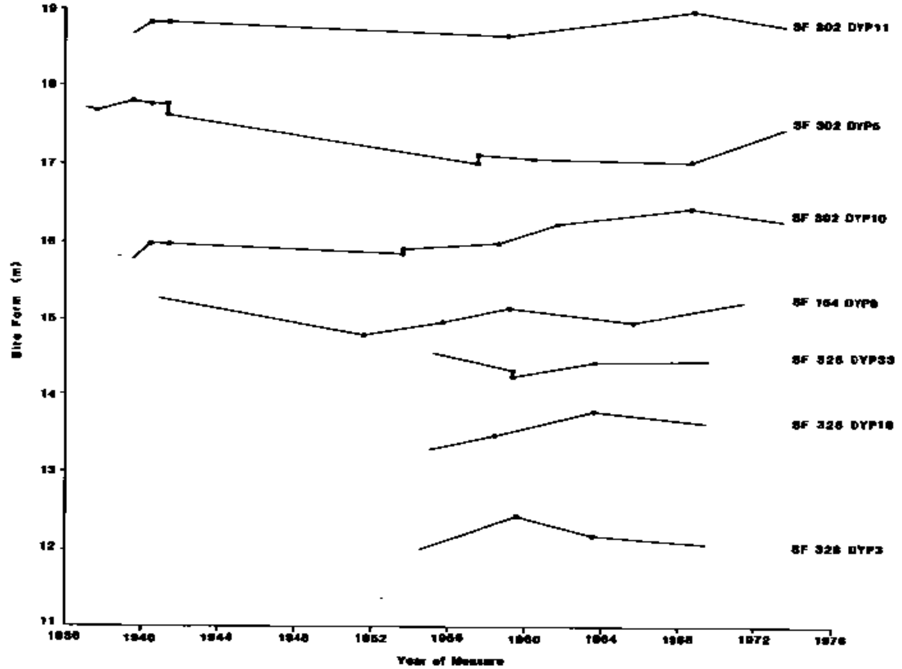

Figure 3. Change in Estimated Site Form over 40 Years.

since last logging and site form. Similarly, estimates of site form were independent of the year of measure, except during the years 1948, 1966, 1967 and 1971, which returned significantly lower estimates. The low estimates of 1948 and 1971 may be attributed to frost damage in 1946 and to the dieback[4] of the early 1970s.

Thinning in even-aged stands of cypress pine has a relatively small effect on site form in the long term. Thinning dense young stands (mean height 6–7 metres and mean d.b.h. 5–7 cm) from 2000 to 200–400 stems per hectare, gives an average reduction of 0.6 metres in site form (maximum observed 1.8 m). However, in stands where the initial stocking exceeds 2000 stems per hectare, thinning may cause substantial decreases in site form estimates (Figure 4). This is consistent with expectations, as selection of retained stems would favour dominants with good crown depth and greater taper. However, further thinning in stands where mean d.b.h. exceeds 15 cm has only a very slight effect on site form. The thinned stands tend to converge to a site form somewhat lower than that estimated from the original pre-thinning stand, while the unthinned stands remain at the same level (Figure 4). Estimates of site form appear to increase as stands enter the zone of intense competition.

Regression analyses revealed a strong positive correlation between site form and tree diameter increment and between site form and stand basal area increment. Site form is a

[4] Cypress dieback has been attributed to waterlogging and should be regarded as a naturally occurring phenomenon arising as a consequence of normal fluctuation in the environment (Lamb and Walsh 1982).

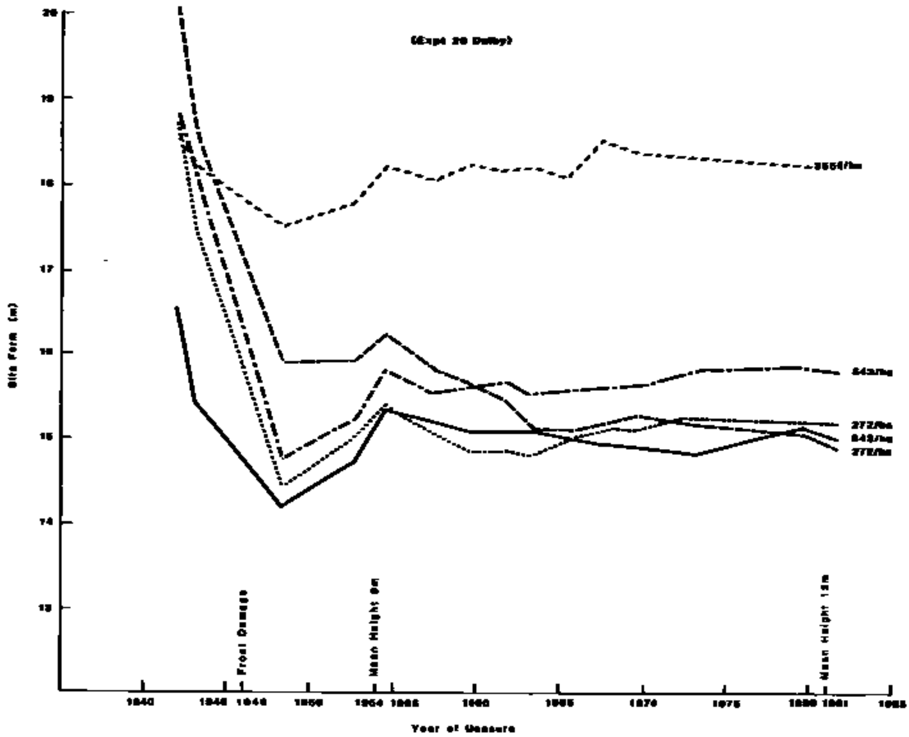

Figure 4. Change in Estimated Site Form after Thinning.

significant variable in the following equations which predict stand basal area and individual tree diameter increments (Vanclay 1985):

$$SBAI = 0.04637\ BA^{1.094} \times e^{0.007402\ BA\ SF - 0.2258\ BA}$$

$$DI = (-0.06357 + 0.007809\ SF) \times e^{-0.08006\ BA} \times D \left[\frac{100^{0.5258}}{D} - 1 \right] \times e^{-0.04421\ D}$$

where *SBAI* is stand basal area accretion *(m²/ha/ann)*, *BA* is stand basal area *(m²/ha)*, *SF* is site form *(m)*, *DI* is diameter increment *(cm/ann)*, and *D* is diameter *(cm dbhob)*.

Johnston (1975), using an equation of the form $Log\ H = a + b\ Log\ D$ found that the gradient of the height-diameter relationship varied with locality, and attributed this to differences in annual precipitation. Thus there is sufficient evidence to suggest that site form is a valid measure of site productivity.

There is one apparent contradiction between the traditional measure of site index and site from in even-aged stands. It is fundamental to the method of site index estimation that height growth depends only upon age and site. In contrast, diameter growth may be dependent upon age, site and stocking (number of trees or basal area per hectare), and this appears to contradict the assumption that site form is independent of stocking. This need not constitute a contradiction if the height-diameter relationship is not affected by stocking. Evidence from four thinning studies in even-aged stands of cypress pine on State Forest 328 indicates that both site form and top height[5] (and hence site index) are influenced by stocking. All sixteen plots in these studies were thinned to the nominated stocking (stems per hectare) in 1941 and maintained at that stocking for the following forty years. In 1981, the effect of stocking was reflected in both site form and top height. A regression of the form $Log\ Y = a + b\ Log\ Stocking$ resulted in a gradient b of 0.126 (standard error 0.016) for site form, and of −0.130 (s.e. 0.027) for top height. This implies that when stocking is doubled, site form will increase by 9%, and top height will decrease by 9%. Evidently, both site index and site form are influenced equally by extremes of stand density. Despite this interaction with stocking, site index has demonstrated great utility as a measure of site productivity in plantations, and there is no evidence that site form is seriously compromised as a measure of site productivity in indigenous forests.

The final requirement for a measure of productivity is that it should be useful. Site form has proven itself in this regard in Queensland. It is a component of the general volume equation (Equation 1) which is superior to, and has replaced the previous regional one-way volume lines. Field staff make extensive use of site form in selecting forest areas to be silviculturally treated. It is an important variable in growth models for yield prediction (Vanclay 1985). Site form has become a fundamental component of the cypress pine yield regulation system, and is routinely determined in all inventory work.

Conclusion

Site form, the expected height of a tree of 25 cm d.b.h.o.b., is shown to be a useful indicator of site productivity in indigenous stands of cypress pine in southern Queensland. Unlike site index, site form is not based on age and thus has potential for assessing site productivity in stands of unknown or uneven age. Further research is warranted to investigate its potential in other forest types.

Acknowledgements

Part of this work was researched at the Commonwealth Forestry Institute in Oxford while one of the authors (Vanclay) was the recipient of a Russell Grimwade Prize. The Trustees of the Russell Grimwade Bequest are thanked for providing this opportunity, and the staff of the C.F.I. Library are thanked for their assistance. Mr. D. M. Wilson, District Forester, Dalby, gave practical support, providing additional data and demonstrating the estimation and use of site form in routine forest management. The referees are also thanked for their constructive criticisms of an earlier version of this paper.

This work forms part of the research and development programme of the Queensland Department of Forestry, and was jointly sponsored by the Divisions of Technical Services and Forest Management Development. Permission to publish this paper is acknowledged.

REFERENCES

ADLARD, P. G. (1980). Growing stock levels and productivity conclusions from thinning and spacing trials in young *Pinus patula* stands in Southern Tanzania. Commonwealth Forestry Institute, Dep. of For., Univ. of. Oxford. Occas. Pap. 8. 17 pp.

[5] Top height is defined as the mean height of the tallest 25 trees per hectare.

ANON (1979). Research Report 1979. Qld Dep. For. 86 pp.

ASSMAN, E. (1961). *Waldertragskunde*. B.L.V., Munchen. English translation by S. H. Gardiner (1970) *The Principles of Forest Yield Study*. Pergamon Press, Oxford. 506 pp.

BRADLEY, R. T., CHRISTIE, J. M. and JOHNSTON, D. R. (1966). Forest management tables. For. Comm. Booklet 16. H.M.S.O. 218 pp.

BRICKNELL, J. E. (1970). Equations and computer subroutines for estimating site quality of eight Rocky Mountain species. USDA For. Serv. Res. Pap. INT–75. 22 pp.

DAWKINS, H. C. (1985). The management of the natural tropical high forest with special reference to Uganda. Imperial Forest Institute, University of Oxford. Inst. Pap. 34. 155 pp.

FETT, J. M. and SMITH, W. J. (1975). Age estimation in cypress pine on the basis of wood anatomy. Paper presented to 17th Forest Products Research Conference, Melbourne, 1975.

GRIMES, R. F. and PEGG, R. E. (1979). Growth data for a spotted gum — ironbark forest in south-east Queensland. Qld Dep. For. Tech. Pap. 17. 30 pp.

HAMMER, G. L. (1981). Site classification and tree diameter height-age relationships for cypress pine in the Top End of the Northern Territory. *Aust. For.* **44**(1): 35–41.

HAMMER, G. L. and ROSENTHAL, K. M. (1978). Frost and minimum temperature probabilities. *Qld Ag. J.* **104**(2): 177–201.

HAVELL, J. J. (1975). Site-vegetation mapping in the northern jarrah forest (Darling Range). 1. Definition of site vegetation types. West. Aust. For. Dept Bull. 86. 115 pp.

HAVELL, J. J. (1980). Application of fundamental synecological knowledge to practical problems in forest management. II. Application. *Forest. Ecol. Manage.* 3(2): 81–111.

JOHNSTON, D. R. and BRADLEY, R. T. (1963). Forest Management Tables. *Commonw. For. Rev.* **42**(3): 217–227.

JOHNSTON, D. R., GRAYSON, A. J. and BRADLEY, R. T. (1967). *Forest Planning*. Faber and Faber, London. 541 pp.

JOHNSTON, T. N. (1975). Thinning studies in cypress pine in Queensland. Qld Dep. For. Res. Pap. 7. 87 pp.

LAMB, D. and WALSH, K. (1982). The effect of salinity and waterlogging on a cypress pine community. Water Research Foundation of Australia Project 79/403. Botany Dept., Univ. of Qld. 33 pp.

LEWIS, N. B., KEEVES, A. and LEECH, J. W. (1976). Yield regulation in South Australian *Pinus radiata* Plantations. Woods and Forests Department, South Australia. Bulletin No. 23. 174 pp.

MacLEAN, C. D. and BOLSINGER, C. L. (1973). Estimating productivity on sites with a low stocking capacity. USDA For. Serv. Res. Pap. PNW–152. 18 pp.

McLINTOCK, T. F. and BICKFORD, C. A. (1957). A proposed site index for red spruce in the northeast. USDA For. Serv. Northeast. For. Expt Stn, Stn Pap. 93. 30 pp.

MADER, D. C. (1965). Volume growth measurement — an analysis of function and characteristics in site evaluation. *J. For.* **38**: 192–198.

MEYER, H. A. (1940). A mathematical expression for height curves. *J. For.* **38**: 415–520.

PIENAAR, L. V. and TURNBULL, K. J. (1973). The Chapman-Richards generalization of von Bertalanffy's growth model for basal area growth and yield in even-aged stands. *For. Sci.* **19**(1): 2–22.

REINHARDT, E. D. (1982). The influence of site quality on the height-diameter relationship of western larch. Unpublished M.Sc. Thesis, Univ. of Montana. 42 pp.

REINHARDT, E. D. (1983). Using height/diameter curves to estimate site index in old-growth western larch stands. Montana Forest and Conservation Expt Stn, School of For., Univ. of Montana. Res. Note 20. 3 pp.

SAMMI, J. C. (1965). An appeal for a better index of site. *J. For.* **63**(3): 174–176.

SHRIVASTA, M. B. and ULRICH, B. (1976). Heredity deals the cards but environment plays the hands — a method of assessing forest site productivity. *Pakistan J. For.* **26**(3): 147–162.

STOUT, B. B. and SHUMWAY, D. L. (1982). Site quality estimation using height and diameter. *For. Sci.* **28**(3): 639–645.

VANCLAY, J. K. (1983). Techniques for modelling timber yield from indigenous forests with special reference to Queensland. M.Sc. Thesis, University of Oxford. 194 pp.

VANCLAY, J. K. (1985). A stand growth model for cypress pine. Paper presented at "Modelling Trees, Stands and Forests" Workshop, Univ. of Melbourne, 26–28 August.

WESTVELD, R. H. (1933). The relation of certain soil characteristics to forest growth and composition in the northern hardwood forest of northern Michigan. Mich. Agr. Expt Stn Tech. Bull. 135. 52 pp.

SETROPA

Specialist Suppliers

TROPICAL *and*
SUB-TROPICAL
FOREST TREE
SEED SPECIES

SETROPA LTD.

P.O. Box 203, 1400 AE Bussum
Holland

CABLES: SETROPA BUSSUM
Phone: 02152-58754
02152-64645
TELEX: 73255 SETRO NL

Timmers & Leyer

P.O. BOX 17, 2100 AA HEEMSTEDE - HOLLAND

We are importers and exporters of Tropical- and Sub-Tropical Tree and Shrub seeds for reforestation and soil improvement purposes.

Please request for a variety list.

Phone : (023) 284340
Cable : timley-heemstede
Telex : 41754 flori nl

established in 1933

When replying to these advertisements, please mention the Commonwealth Forestry Review.